ERDC/CRREL TR-00-4

Cold Regions Research and Engineering Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Evaluation of Photovoltaic Panels at the South Pole Station

Christopher R. Williams and John Rand

April 2000

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Abstract: For this study, commercially available photovoltaic (PV) panels of similar mechanical and electrical characteristics were procured from four manufacturers, and their structural survivability and electrical performance were evaluated in the extreme harsh environment of the South Pole, on the rooftop of the newly constructed Atmospheric Research Observatory (ARO). The PV panels were installed for 410 days. During that time, they were exposed to varying amounts of inclement weather. Temperatures ranged from a low of –70 to a high of –20°C, with average wind speeds of approximately 5 m s^{-1}, gusting to 20 m s^{-1}. Prior to removal, each PV panel was inspected to see if the harsh environment degraded the structural characteristics of the panel frame, glazing, panel backing, and junction box. The inspection showed that the PV panels had not noticeably degraded during the 410-day exposure. The electrical performance of the PV panels depended on two factors: sun angle and visibility. On days with cloud cover or windblown snow, the PV panels' output power was reduced significantly. With sun angles approaching the highest limits and visibility being high, the PV panels approached their rated output power.

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PREFACE

This report was prepared by Christopher R. Williams, Electronic Engineer, Engineering Resources Branch, and John Rand, South Pole Engineering Project Manager, U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory. Funding for this work was provided by the National Science Foundation.

Technical review was conducted by George Blaisdell and James Morse, both of CRREL.

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CHRISTOPHER R. WILLIAMS AND JOHN RAND

INTRODUCTION

The goal of this study was to procure commercially available photovoltaic (PV) panels of similar mechanical and electrical characteristics from four manufacturers and to evaluate their structural survivability and electrical performance in the extreme harsh environment of the South Pole. The PV panels were evaluated on the rooftop of the newly constructed Atmospheric Research Observatory (ARO) at the South Pole Station.

APPROACH

CRREL and the Antarctica Support Association (ASA) worked together to evaluate the panels. In Fiscal Year (FY) 1997, CRREL's tasks were as follows:

- Identify and procure selected PV panels.
- Inspect and evaluate PV panels at CRREL.
- Develop an evaluation plan and forward it for review.
- Procure necessary instrumentation for analysis.
- Ship components for vessel delivery to McMurdo.

ASA's tasks were to incorporate the PV panels into the new ARO building and review the evaluation plan.

In FY 1998, CRREL:

- Inspected the PV panels at South Pole Station prior to placement on the ARO building.
- Set up monitoring equipment.
- Provided monthly status reports during the austral summer.
- Provided a postseason report on the PV panel installation.

ASA assisted in mounting the PV panels to the new ARO building and running monitoring cables within the facility. They also provided a technician to assist in forwarding data.

In FY 1999, CRREL:

- Provided monthly status reports.
- Inspected the PV panels after the winter.
- Removed the PV panels from the ARO and returned them to CRREL.
- Provided final report at the conclusion of the austral summer.

ASA provided a technician to help remove the PV panels and monitoring equipment.

The evaluation plan developed in FY 1997 laid out the following goals:

- Compare the mechanical and electrical specifications of the selected commercially available PV panels.
- Develop evaluation criteria to determine the structural survivability of each PV panel.
- Develop evaluation criteria to determine the electrical performance of each PV panel.

In addition, it detailed how the PV panels were to be mounted and gave the specifications for the data acquisition system and data logger program.

METHODS

Platform configuration

The evaluation platform was the four sides of the new ARO building (Fig. 1) at the South Pole Station, Antarctica. The PV panels from the four manufacturers are approximately the same physical size and shape, which facilitated easy comparison. In addition, the method of attachment to the exterior surface of the ARO building allowed for easy installation, removal, and structural evaluation.

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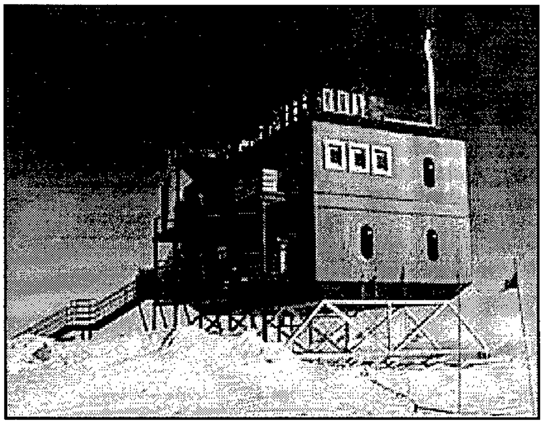
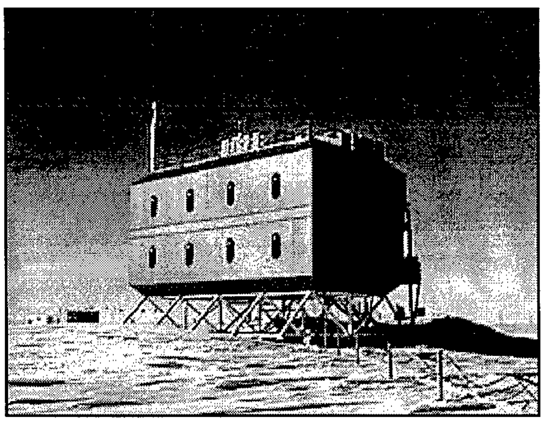
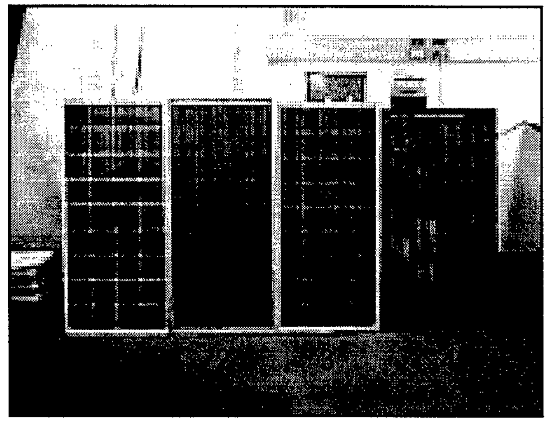


a. Southeast corner.

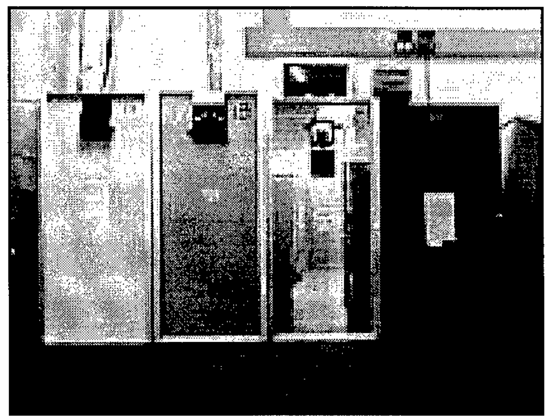


b. Northwest corner.

Figure 1. Atmospheric Research Laboratory (25 November 1997).



a. Front view.



b. Rear view.

Figure 2. PV panels that were evaluated (1—KYOCERA; 2—PhotoComm; 3—ASE Americas; 4—Solarex).

Mechanical and electrical specifications for each PV panel

The PV panels (Fig. 2) selected for the test were purchased from four manufacturers—KYOCERA, Photo Comm, Inc., ASE Americas, and Solarex. The following PV panel mechanical and electrical specifications came directly from the manufacturers' data sheets (Table 1).

KYOCERA model LA-51

These cells are encapsulated between a tempered glass cover and an EVA pottant, with PVF and aluminum foil back sheets to provide maximum protection from the most severe environmental conditions. The entire laminate is installed in an anodized aluminum

Table 1. Specifications of PV panels tested.

	KYOCERA		*PhotoComm*		*ASE Americas*		*Solarex*	
Surface area (in.^{2}, m^2)	679	0.438	674.1	0.436	676.4	0.436	676.4	0.436
Length (in., mm)	38.8	985	38.3	973	38.0	965	36.9	937
Width (in., mm)	17.5	445	17.6	448	17.8	452	19.74	502
Thickness (in., mm)	1.4	36	1.75	44	2.0	51	2.0	51
Weight (lb, kg)	13	5.9	12	5.4	13.5	6.12	13.9	6.31
Rated power (W)	51		47.2		50		50	
Voltage (nominal) (V)	16.9		17.1		17		12	
Current (test) (A)	3.02		2.8		2.9		3.12	
Voltage (Voc) (V)	21.2		21.2		20.7		21.1	
Current (Isc) (A)	3.25		2.9		3.2		3.17	

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frame to provide structural strength and ease of installation.

PhotoComm, Inc., model DV-50-N

Duravolt non-glass solar electric modules are designed specifically for use in rough environments, where typical glass solar modules are prone to breakage. Duravolt modules are constructed with highly efficient, multicrystalline solar cells laminated between an aluminum backplate and face covering of clear Tefzel fluropolymer resin by DuPont. The module is framed with rugged anodized aluminum, which features a captive nut channel for easy installation. Fully gasketed and sealed for maximum protection from rain and condensation, this design eliminates gaps in the gasket corners.

ASE Americas model ASE-50-AL

These devices have 36 crystalline (EFG) silicon solar cells, 100 mm square, that are series connected. The encapsulant is an advanced proprietary substance (not EVA), while the front is tempered, $^{1}/_{8}$-in.- (3.2-mm-) thick, low iron glass. The back skin is heavy duty, 0.005-in. (0.127-mm) aluminum foil. The frame is aluminum, and the junction box accommodates a variety of cables. The terminal block allows for both series and parallel module to module wiring, with wire sizes ranging from no. 4 to no. 18 awg. Factory installed bypass diodes are in place for every 18 cells connected in series.

Solarex model MSX-50

This device has a heavy duty frame, made up of corrosion resistant aluminum, with a bronzed, anodized finish. It has the following features:

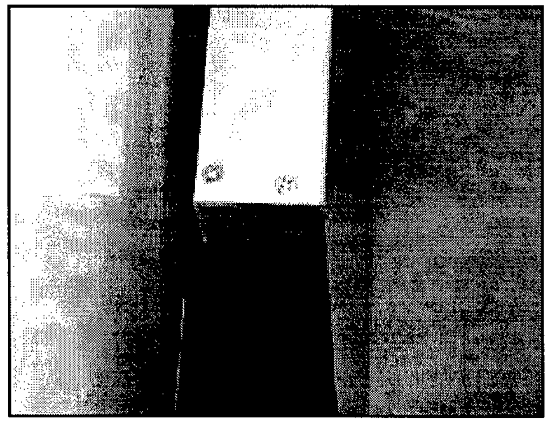
- Weatherproof junction box, NEMA 4X, UL rated terminal box, mounted to frame, not the module back, that accepts bypass blocking diodes.
- True power rating, every module tested, labels for both standard and field operating conditions (watts, volts, amps).
- Internal bussbar located outside cell area improves safety and module life.
- UL listed for electrical and safety (class C fire rating).
- FM Approved for use in NEC Class 1, Division 2, Group D hazardous locations.

PV panel aluminum frame

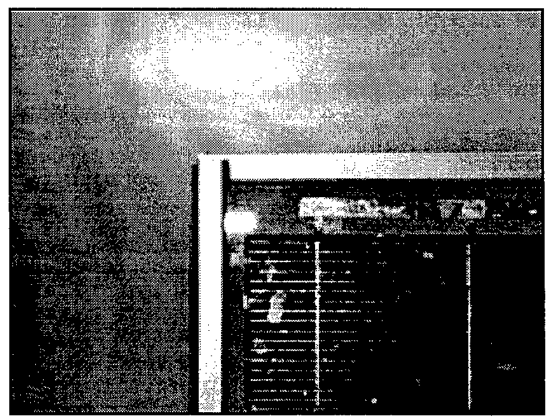
Each of the four manufacturer's PV modules is surrounded by a frame. The frame consists of four pieces of extruded aluminum fastened at the top and bottom corners by sheet metal screws. Figures 3–6 depict the various styles of corner connections surrounding the PV modules.

Structural survivability of each PV panel

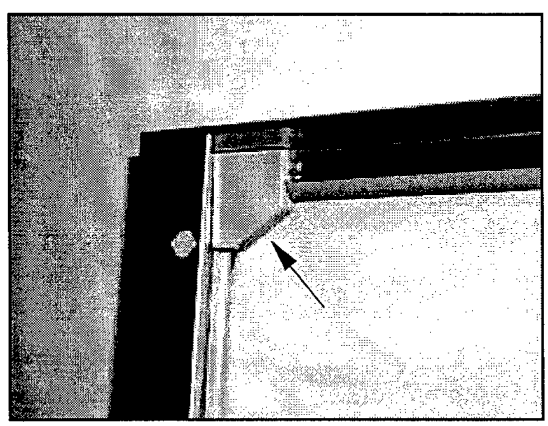
The PV panel mechanical structure was inspected prior to installation and removal from the ARO build-



a. Top view of corner connections (flat head sheet metal screws).

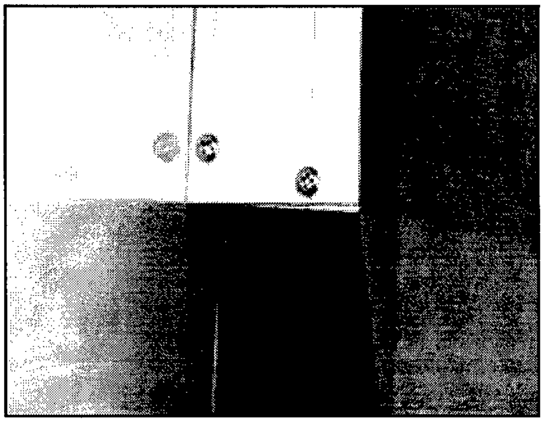


b. Front view of corner connections.



c. Back view of corner connections (arrow points to plastic environmental seal cap; extruded channel is closed).

Figure 3. Details of KYOCERA panel.

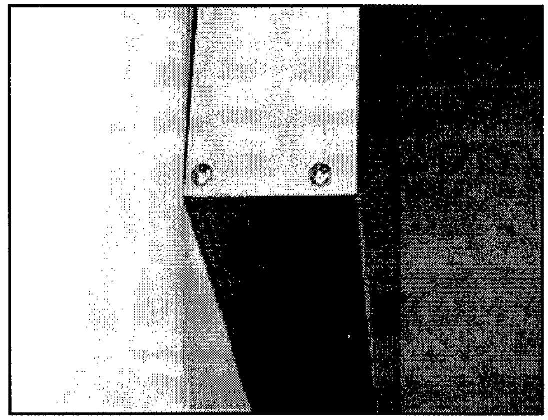


a. **Top view of corner connections (pan head sheet metal screws).**

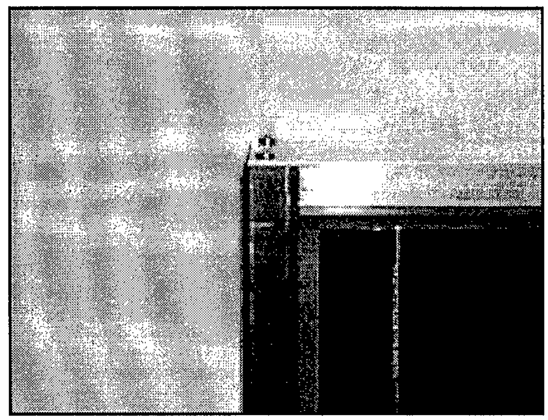
b. Front view of corner connections.

c. Back view of corner connections (arrow points to sheet metal screw in open extruded channel).

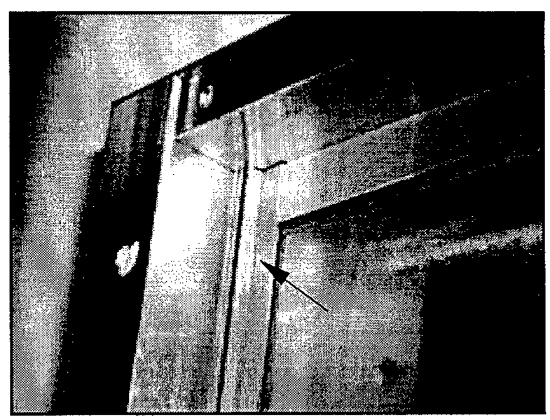
Figure 4. Details of PhotoComm, Inc., panel.



a. Top view of corner connections (pan head sheet metal screws).



b. Front view of corner connections.



c. Rear view of corner connection (arrow points to sheet metal screw in open extruded channel).

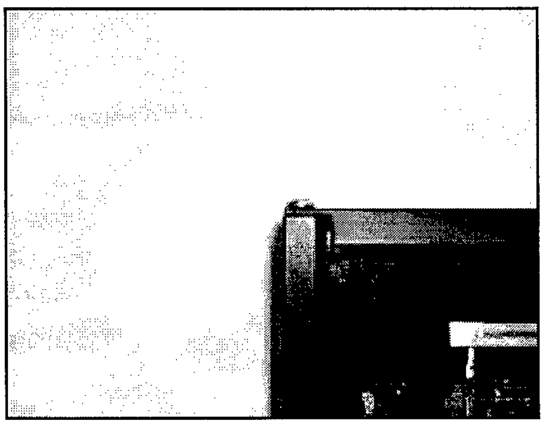
Figure 5. Details of ASE Americas panel.

ing roof top. Areas of interest were the general construction of the PV panel frame, glazing, backing, and electrical junction box. If any abnormalities were found with a PV panel, a description of it was noted.

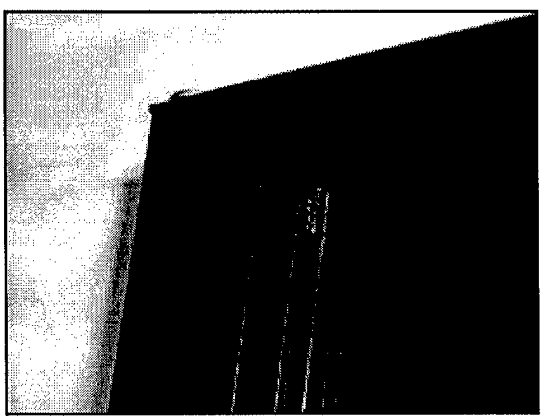
Procedures for determining the electrical performance of each PV panel

A data acquisition system was installed to monitor the electrical performance of each PV panel, the avail-

a. Top view of corner connection (pan head sheet metal screws).



b. Front view of corner connection



c. Back view of corner connection (arrow points to sheet metal screw in open extruded channel).

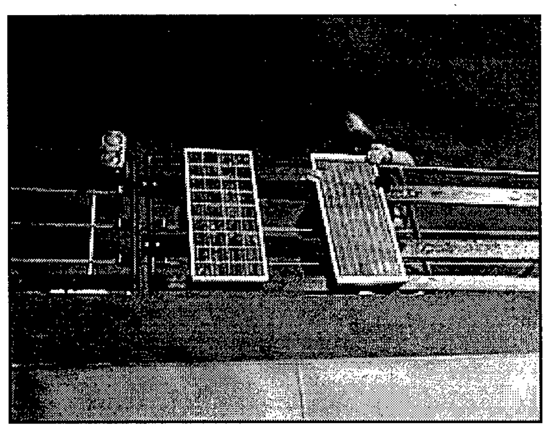
Figure 6. Details of Solarex panel.

able power output and panel temperature being the main parameters of interest. Ambient air temperature and net radiation levels were also measured. All parameters were sampled every 15 minutes and averaged hourly by the data acquisition system during the 1997–98, 1998–99 austral summers (23 September to 22 March).

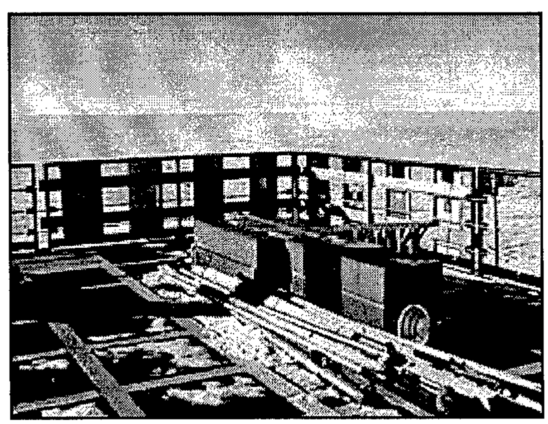
Once a month during the austral summer, a technician from ASA downloaded the data and sent them to a designated CRREL representative via E-mail. Upon receipt, the new monthly data were appended to a common data file for processing.

Details for mounting the panels

Each PV panel was mounted vertically on the ARO roof top handrails (Fig. 7). Predrilled plywood strips were added to the handrails to make it easier to install and remove them. The panels were bolted to the plywood strips using holes in the aluminum frame provided by the manufacture. Each side of the ARO building received one PV panel from each manufacturer. Table 2 gives PV panel numbering and placement on the ARO roof handrails.



a. Work in progress.



b. Mounted panels.

Figure 7. Mounting PV panels on ARO roof top handrails.

Table 2. PV panel numbering and placement.

ARO mounting location	PV Panel	Manufacturer	Model number
South Side	1A	KYOCERA	LA-51
	1B	PhotoComm Inc.	DV-50-N
	1C	ASE Americas	ASE-50-AL
	1D	Solarex	MSX-50
East Side	2A	KYOCERA	LA-51
	2B	PhotoComm Inc.	DV-50-N
	2C	ASE Americas	ASE-50-AL
	2D	Solarex	MSX-50
North Side	3A	KYOCERA	LA-51
	3B	PhotoComm Inc.	DV-50-N
	3C	ASE Americas	ASE-50-AL
	3D	Solarex	MSX-50
West Side	4A	KYOCERA	LA-51
	4B	PhotoComm Inc.	DV-50-N
	4C	ASE Americas	ASE-50-AL
	4D	Solarex	MSX-50

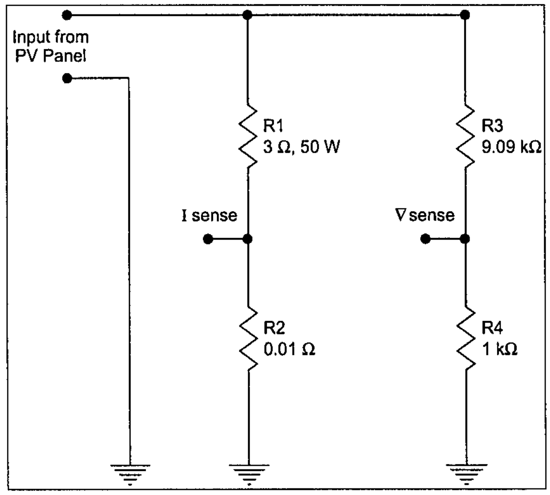


Figure 8. Half bridge network.

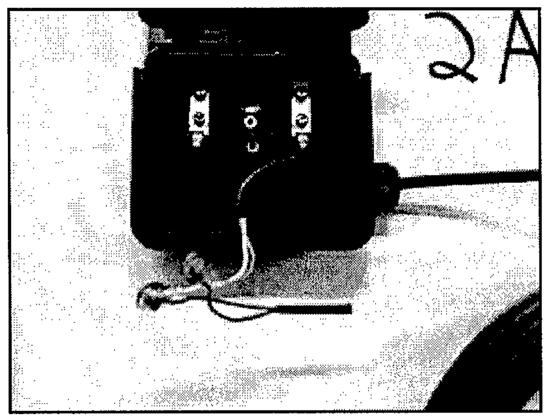


Figure 9. PV panel junction box (note panel output terminals, splices, and thermistor).

Data acquisition system, signal conditioning, and PV panel heating temperature sensor

The data acquisition system consisted of a datalogger (CR10X), two multiplexers (AM416), a storage module (SM716), a power supply (PS12LA), and signal conditioning circuitry, all housed in an enclosure. The datalogger, multiplexer, storage module, power supply, and enclosure are all products of Campbell Scientific of Logan, Utah. The signal conditioning circuitry was designed and built by CRREL engineers and technicians.

The signal conditioning circuitry is an interface between the PV panel and the input channels of the datalogger. This circuitry consists of two half bridge networks (Fig. 8) for each PV panel. The half bridge networks are used to scale the PV panels' output voltage to an acceptable range for the datalogger input channels. One half bridge is used to determine the PV panels' output power by measuring current through a 3-Ω load via a sense resistor, while the second is used to determine the PV panels' output voltage potential.

Connected from the data acquisition system to each PV panel is a 20-awg four-conductor wire. Two of the conductors (red, black) are attached to the PV panels' output terminals, which are located in the junction box on the back of the panel (Fig. 9). The remaining two conductors (green, white), terminating in the same junction box, are attached to a thermistor (107B temperature sensor) that senses the PV panels' temperature.

Datalogger program

A program (SOLARB.CSI), written for the datalogger with Campbell Scientific PC208 software, controls all aspects of sampling and processing of the PV panels' electrical performance. The PV panel electrical output is measured every 15 minutes and is averaged and stored hourly.

Net radiometer

A net radiometer (Fig. 10), manufactured by Radiation and Energy Balance Systems Inc., model Q-7, was used to sense the net radiation values present at the ARO building. The Q-7 is a high-output thermopile sensor. The thermopile sensor measures the algebraic sum of incoming and outgoing all-wave radiation (i.e., short- and long-wave components). Incoming radiation is made up of three components—direct beam and diffuse solar radiation plus long-wave irradiance from the sky. Reflected solar radiation plus the terrestrial long-wave radiation make up the outgoing all-wave radiation. Net radiation has the units of W m^{-2}.

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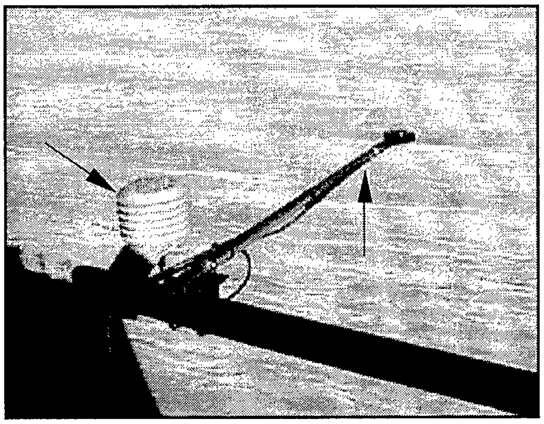

Figure 10. Temperature sensor with radiation shield (left arrow) and Q-7 net radiometer in horizontal position (right arrow).

Ambient air temperature

The ambient air temperature sensor (Fig. 10) uses the same thermistor (107B temperature probe) as does the PV panel temperature sensor. Like the PV panel heating sensor, the ambient air temperature sensor was polled by the CR10X's P4 instruction. Unlike the PV panel temperature sensor, a solar radiation shield has been added to ensure that the true ambient temperature was measured.

RESULTS

PV panel inspection prior to installation

KYOCERA, LA-51

No obvious defects were found in the KYOCERA PV panel. The aluminum frame surrounding the PV module and glazing exhibited great strength. When a twisting motion was applied to this PV panel, the aluminum frame barely flexed. The glazing, panel back, and junction box were all free of defects.

PhotoComm, Inc., DV-50-AL

On all four of the PhotoComm, Inc., panels that we inspected, the gasketed seal between the glazing and aluminum frame showed signs of failure. The gasketed seal was pulling out of the corners between the glazing surface and aluminum frame. Each panel showed some signs of aluminum frame weakness. The corner connections of the frame were loose and allowed considerable movement when a twisting motion was applied. Three of the frames showed signs of abuse; they had dents and or were bent. The glazing, panel back, and junction box were all free of defects.

ASE Americas, ASE-50-AL

The ASE Americas' panels are well built. No defects were detected from a visual inspection. The aluminum frame surrounding the PV module and glazing was very tight and had only slight movement when a twisting motion was applied. The glazing, panel back, and junction box were all free of defects.

Solarex, MSX-50

The Solarex panels also showed no signs of any structural defects. The aluminum frame experienced very little flex when a twisting motion was applied. The aluminum frame was tight to the PV module and glazing surface. The glazing, panel back, and junction box were all free of defects.

Measure of PV panel flex

To determine the flex (rigidness) of a PV panel, a simple fixture was constructed. It held three corners of the PV panel in a fixed position, while the fourth corner was left free to allow the PV panel to be pulled to simulate a twisting motion. Each PV Panel that was tested had approximately 8 lb (35.6 N) of tension applied to the free corner. The deflection attributable to the twisting motion was then recorded (Table 3).

Table 3. PV panel flex.

PV panel	Deflection (in.)	(cm)
KYOCERA	0.375	0.9525
ASE Americas	0.500	1.27
Solarex	0.750	1.905
PhotoComm	1.125	2.858

Processed data

All data sent from the South Pole from 25 November 1997 to 2 December 1998 have been processed into one data file. That data file has been analyzed to provide following.

- Performance of all PV panels from 25 November 1997 through 2 December 1998.
- Performance of all PV panels over 24 hours on a high-visibility day.
- Performance of all PV panels over 24 hours on a low-visibility day.
- Net radiometer readings from 25 November 1997 to 2 December 1998.
- Situation report (SITREP) data, 1997–1998.

Overall PV panel performance

Figures A1–A16 were created to show the performance of each PV panel. PV power output and PV panel temperature are parameters of interest. The readily available PV power coincided with the sun declination angle. At the highest sun declination angle (23.5°), the PV panels exceeded or approached their rated PV power output. As available PV power increased, PV panel heat-

ing followed. Like PV power, PV panel heating coincided with the sun declination angle. PV panel temperatures experienced tens of degrees increases above ambient South Pole temperatures at the highest sun declination angle.

24-hour PV panel performance on a high-visibility day

A 24-hour period on a high-visibility day (11–12 January 1998) was selected to compare the PV panels' performance (Table 4). Figure 11 begins with the south side of ARO receiving the unobstructed sunlight. As the 24-hour period progressed, peak PV panel performance changed as each side of ARO received direct sunlight (Table 5). The available PV power output levels listed in Table 4 were chosen when the sun azimuth angle was approximately perpendicular to the sides of ARO. For three out of the four peak periods, PV panel C produced the highest available output power. PV panel D consistently produced the lowest available PV output power, while panels A and B flip-flopped between second and third, with the exception of the south side of ARO, when PV panel B was first and A was second.

24-hour PV panel performance on a low-visibility day

A 24-hour period on a low-visibility day (13–14 January 1998) was also selected to compare the PV panels' performance (Table 6). During this 24-hour period, the visibility at the south pole was recorded as being 0.25 miles or less. Figure 12 begins with the south side of the ARO receiving the obstructed sunlight. The available output power of all the PV panels remained low during this period. Because of the low visibility, it was difficult to identify any particular PV panel as outperforming the next. At the end of the 24-hour period, when the visibility increased and sun faced the north side of ARO, there was greater available output power from the PV panels. PV panel C produced the highest available output power, while PV panel D produced the lowest. PV panels B and A came in second and third.

Table 4. High-visibility day PV panel performance.

ARO mounting location	PV panel	Measured output power (W)	Rated output power (W)
South Side	1A	26.8	51.0
	1B	27.7	47.2
	1C	26.8	50.0
	1D	25.4	50.0
East Side	2A	49.7	51.0
	2B	50.2	47.2
	2C	51.9	50.0
	2D	43.5	50.0
North Side	3A	50.1	51.0
	3B	49.4	47.2
	3C	50.8	50.0
	3D	42.6	50.0
West Side	4A	45.5	51.0
	4B	47.0	47.2
	4C	51.2	50.0
	4D	44.1	50.0

Table 5. Sun azimuth angle.

PV panel set	ARO side designation	Grid angle perpendicular to ARO sides (degrees)	Time of greatest available power output (hours)
1	South	200	1100–1200
2	East	110	1700–1800
3	North	20	2300–0000
4	West	290	0500–0600

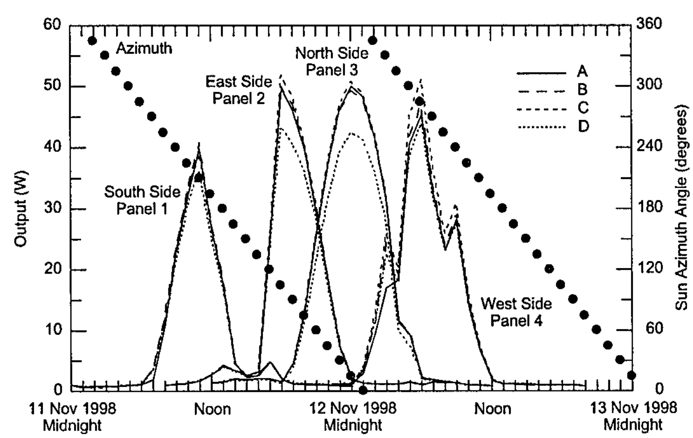

Figure 11. PV panel performance on the high-visibility day (11 to 12 January 1998) over 24 hours.

Table 6. Low-visibility day PV panel performance.			
ARO mounting location	PV panel	Measured output power (W)	Related output power (W)
South Side	1A	2.0	51.0
	1B	2.1	47.2
	1C	2.0	50.0
	1D	2.1	50.0
East Side	2A	1.5	51.0
	2B	1.5	47.2
	2C	1.5	50.0
	2D	1.5	50.0
North Side	3A	1.8	51.0
	3B	1.8	47.2
	3C	1.8	50.0
	3D	1.6	50.0
West Side	4A	20.4	51.0
	4B	21.0	47.2
	4C	22.3	50.0
	4D	20.0	50.0

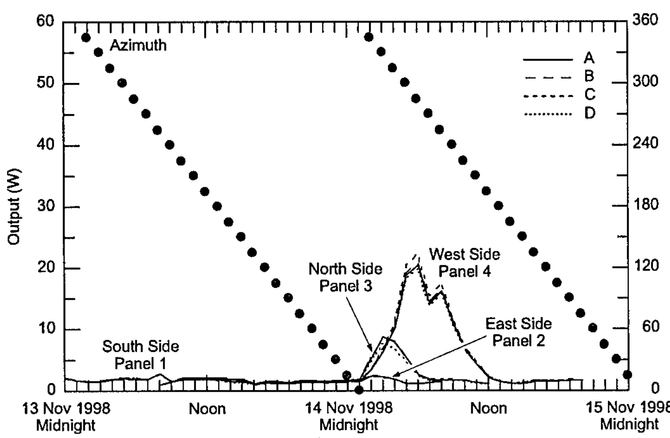

Figure 12. PV panel performance on the low-visibility day (13 to 14 January 1998) over 24 hours.

Net radiometer readings

To get an understanding of the amount of potential power available for the PV panels, the net radiation values were measured. The intensity of the available potential power depends on the sun declination angle and visibility. At the highest sun declination angle, net radiation values reached a potential of 250 W m^{-2} in the horizontal position. Figure 13 shows the net radiation values during the austral summers.

SITREP98 data

The source of the SITREP98 data was the South Pole weekly climatological summary, which provides uninterrupted temperature and wind speed data from 22 November 1997 to 12 December 1998. Figure 14 depicts the extreme temperatures to which the PV panels were exposed. Temperatures ranged from approximately –20 to –70°C.

Figure 15 shows the average wind speed and gusts that the PV panels had to endure. The PV panels were exposed to a constant wind speed of approximately 5 m/s, with gusts up to 20 m/s.

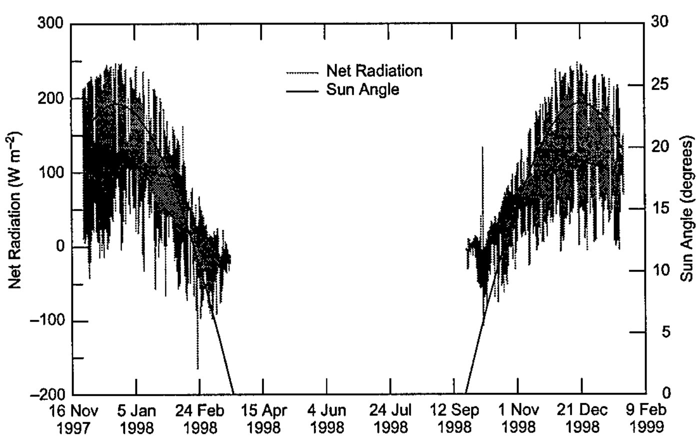

Figure 13. Net radiometer readings from 25 November 1997 to 23 January 1999.

Austral summer 1998–1999

On or about 20 September 1998, the sun broke the horizon at the South Pole. John Booth of ASA reported the following at ARO on 22 September 1998:

- South side of ARO (Fig. 16a): PV panels were uniformly covered by snow about 1 in. thick.
- East side of ARO (Fig. 16b): PV panels had a snow cover ranging from negligible to about 1 in. thick, in what were obviously wind-driven striations. The buildups were at levels downwind (laterally, to the south) where supports had caught and held snow. These supports are the things on which the PV panels are mounted, I believe. Anyway, perhaps slightly more than 50% of each PV panel was obscured.
- North side of ARO (Fig. 16c): Negligible snow covered most of the PV panel, a few tenths of an inch (about a half centimeter) at the very bottoms.
- West side of ARO (Fig. 16d): There was a uniform covering of about 1/3 in. (about 1 cm) over all panels.

On 21 September 1998, John swept away the accumulated snow from the PV panels with a broom. Remaining on each was a light frosting of ice. On 1 October 1998, John reported that the ice layer had been removed by the sun and drying wind.

PV panel removal and evaluation

On 24 January 1999, the PV panels and data acquisition system were removed from the ARO building. The PV panels had been exposed to the harsh environment of the South Pole for 410 days. Prior to being packed for the return shipment to CRREL, each PV panel was thoroughly inspected for structural degradation of the PV module and aluminum frame. The findings are listed below.

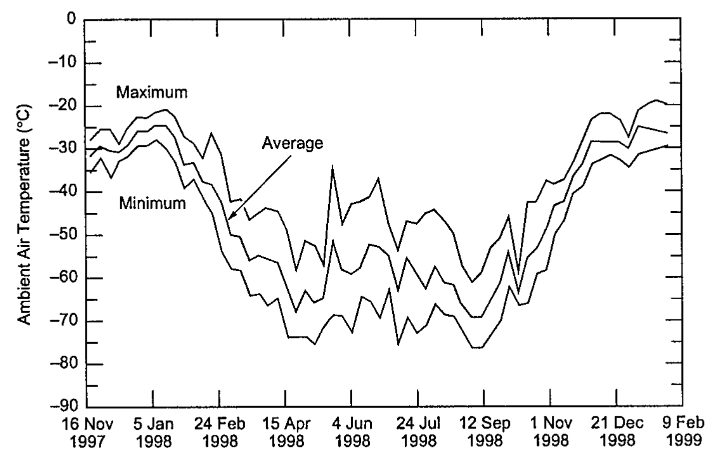

Figure 14. Temperatures experienced by ARO from 16 November 1998 to 9 February 1999.

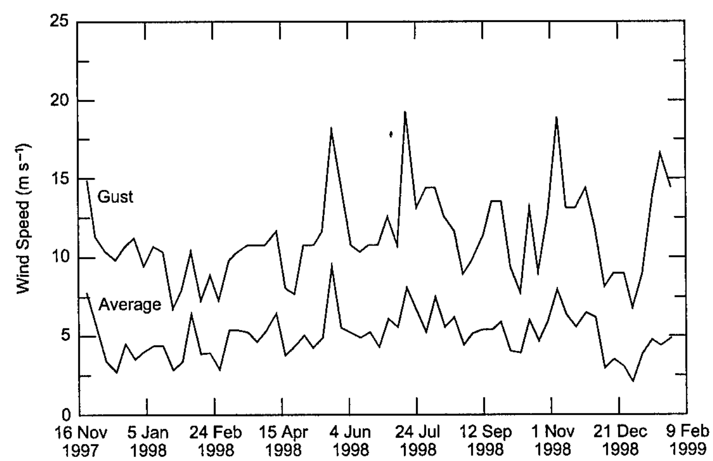

Figure 15. Wind speeds experienced by ARO from 16 November 1998 to 9 February 1999.

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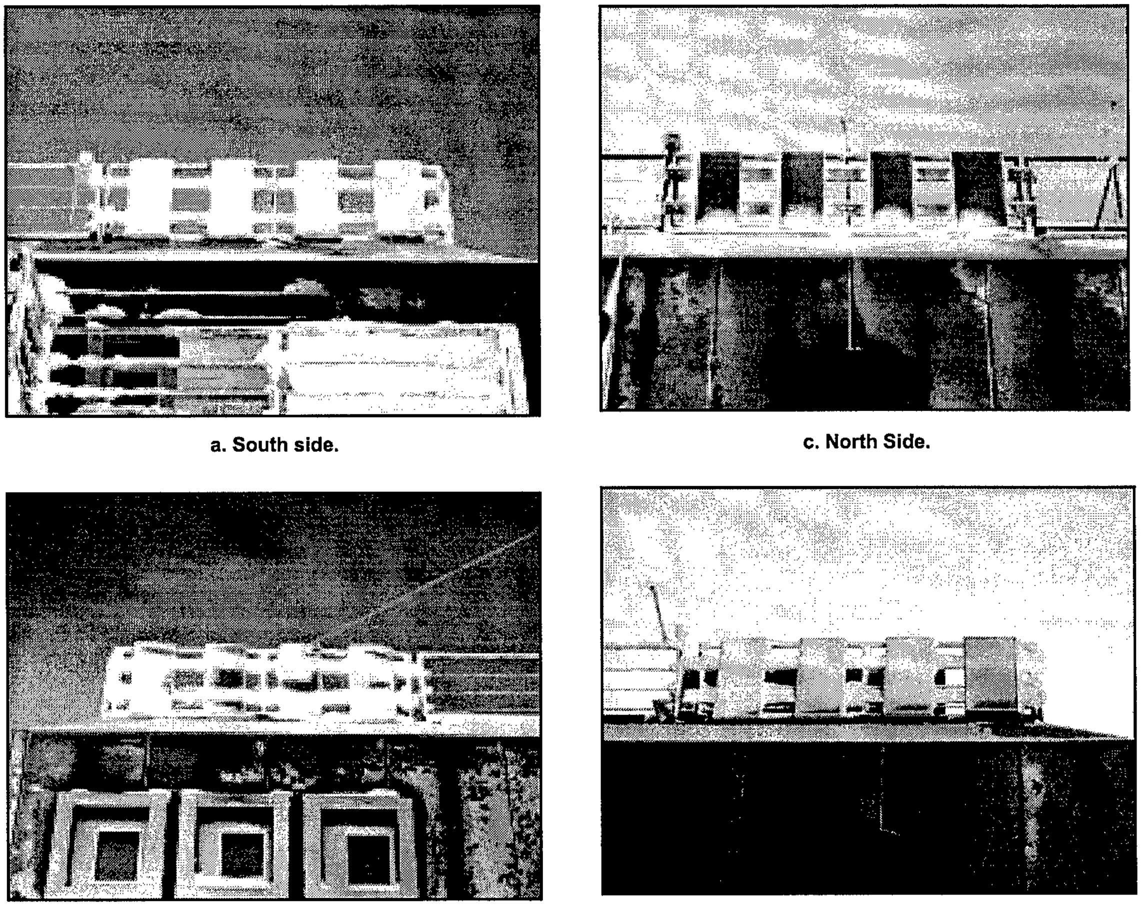

a. South side.

c. North Side.

b. East side.

d. West side.

Figure 16. Conditions at ARO on 22 September 1998.

KYOCERA

There was no noticeable structural degradation of the PV module or aluminum frame.

PhotoComm, Inc.

There was no noticeable structural degradation of the PV module or aluminum frame.

ASE Americas

The color of the foil backing behind the crystalline silicon cells changed from a gray to a light brown. Other than the discoloration of the foil backing, there was no noticeable structural degradation of the PV module or aluminum frame.

Solarex

There was no noticeable structural degradation of the PV module or aluminum frame.

The electrical performance and construction ratings in Table 7 have been assigned a range from one to four, one being the highest and four the lowest. The electrical performance ratings were based on the data recorded during the 24-hour period of PV panel performance on a high visibility day. The construction rating was based on general observations and the data recorded from the PV panel flex test.

CONCLUSION

The PV panels were installed on the ARO building at the South Pole station for a total of 410 days. During that time, the panels were exposed to varying amounts of inclement weather. Temperatures ranged from a low of –70 to a high of –20°C, with average wind speeds of approximately 5 m/s, gusting to 20 m/s. Prior to removal, each PV panel was inspected to see if the harsh environment degraded the structural characteristics of the panel frame, glazing, panel backing, and junction box. The inspection showed that the PV panels had not noticeably degraded during the 410-day exposure.

The electrical performance of the PV panels depended on two factors: sun angle and visibility. As expected, the

Table 7. Ratings assigned to the test PV panels.

PV panel	Power (W)	Current (A)	Voltage (V)	Glazing	Size	Weight	Cost (dollars)	Electrical performance	Construction rating
KYOCERA	51	3.02	16.9	Glass	38.8 × 17.58 × 1.4 in. 98.55 × 44.65 × 3.56 cm	13 lb 5.9 kg	238	3	1
PhotoComm	47.2	2.8	17.1	Tefzel	38.38 × 17.68 × 1.75 in. 97.48 × 44.91 × 4.45 cm	12 lb 5.4 kg	350	2	4
ASE Americas	50	2.9	17	Glass	38.8 × 17.88 × 2 in. 98.55 × 45.42 × 5.08 cm	13.5 lb 6.1 kg	277	1	2
Solarex	50	3.12	12	Glass	36.98 × 19.758 × 2 in. 93.93 × 50.185 × 5.08 cm	13.9 lb 6.3 kg	285	4	3

output performance of the PV panels followed the angle of the sun. Visibility also contributed to the PV panel output power level. On days with cloud cover or wind-blown snow, the PV panels' output power was reduced significantly. With sun angles approaching the highest limits and visibility being high, the PV panels approached their rated output power.

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APPENDIX A: PV PANEL PERFORMANCE

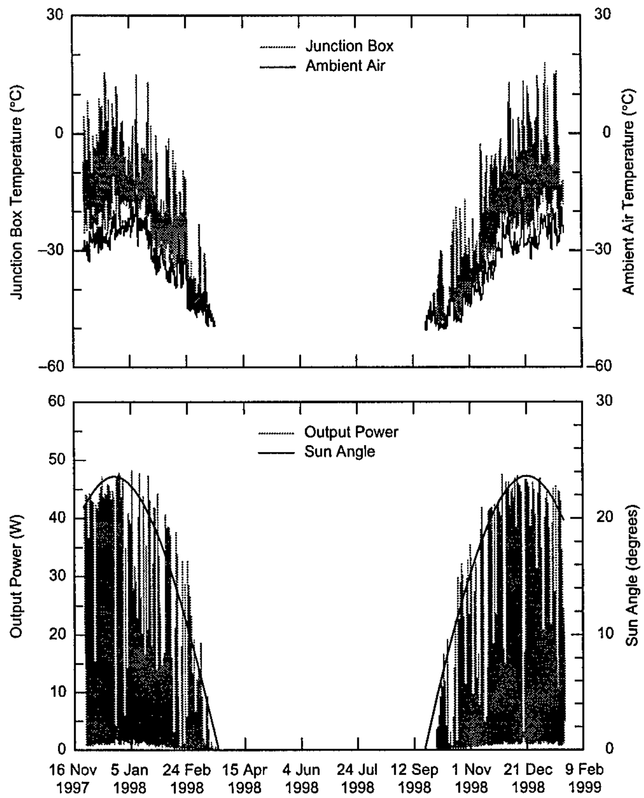

Figure A1. Performance of PV panel 1A from 25 November 1997 to 23 January 1999.

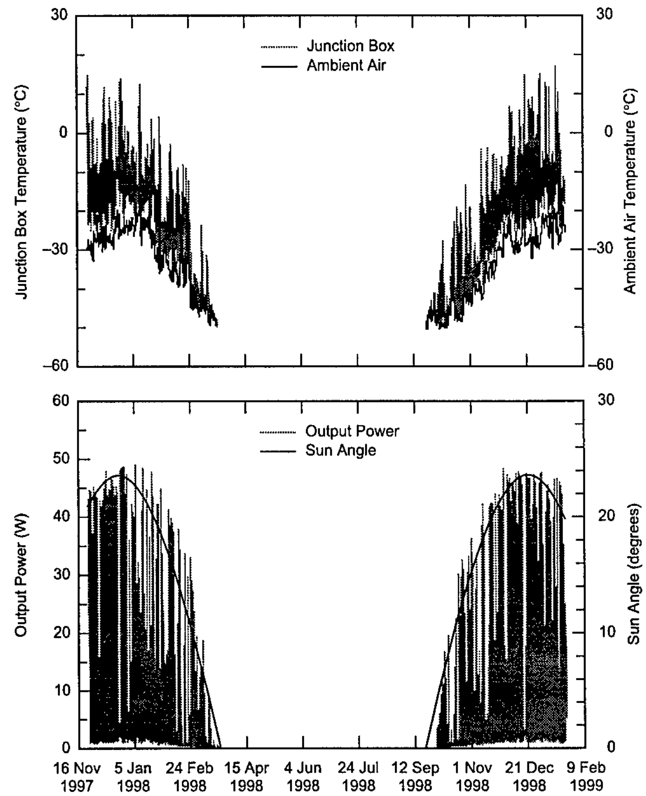

Figure A2. Performance of PV panel 1B from 25 November 1997 to 23 January 1999.

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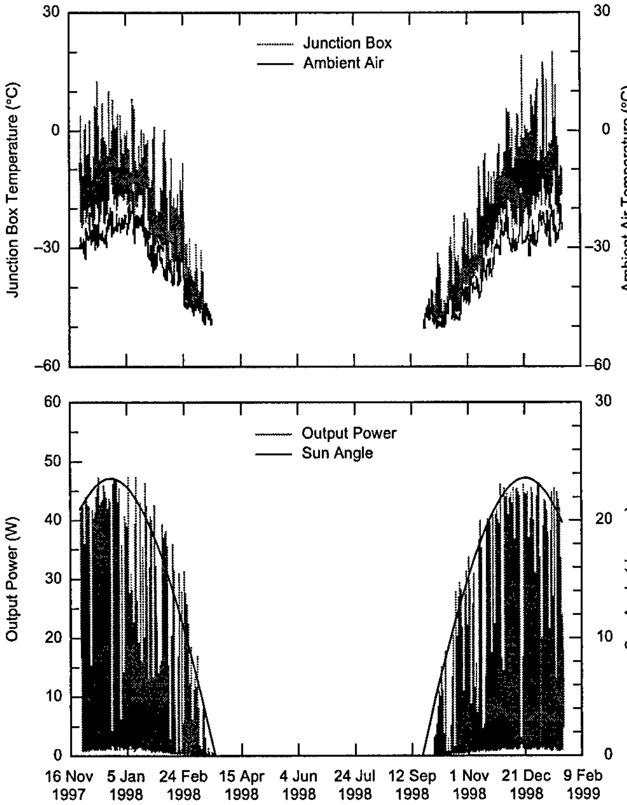

Figure A3. Performance of PV panel 1C from 25 November 1997 to 23 January 1999.

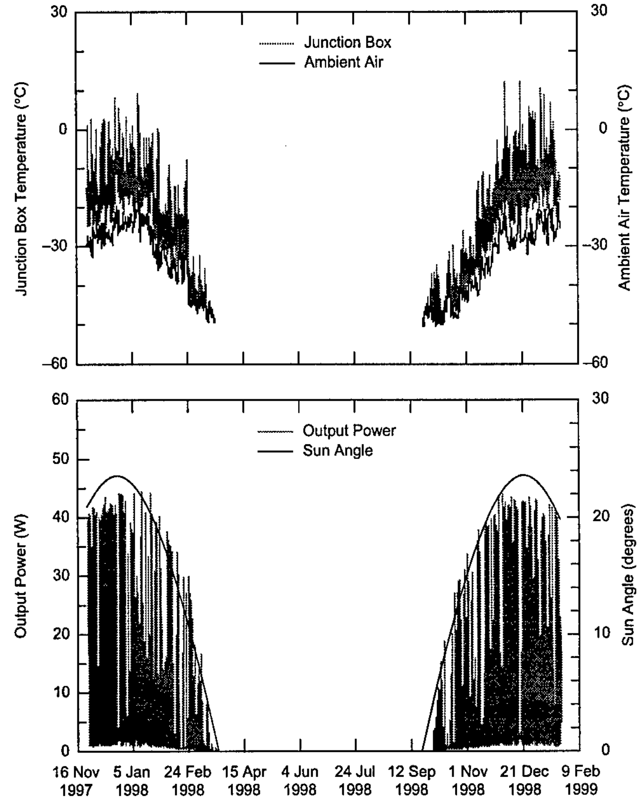

Figure A4. Performance of PV panel 1D from 25 November 1997 to 23 January 1999.

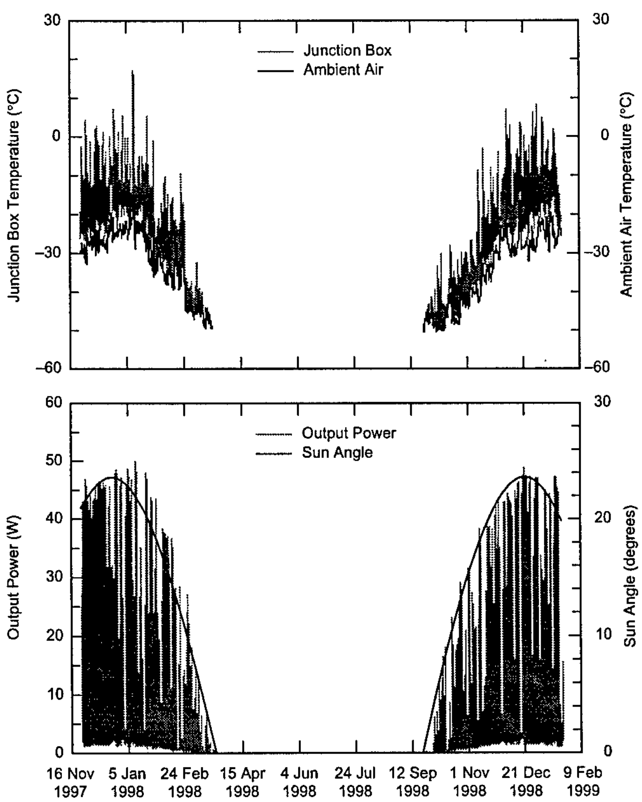

Figure A5. Performance of PV panel 2A from 25 November 1997 to 23 January 1999.

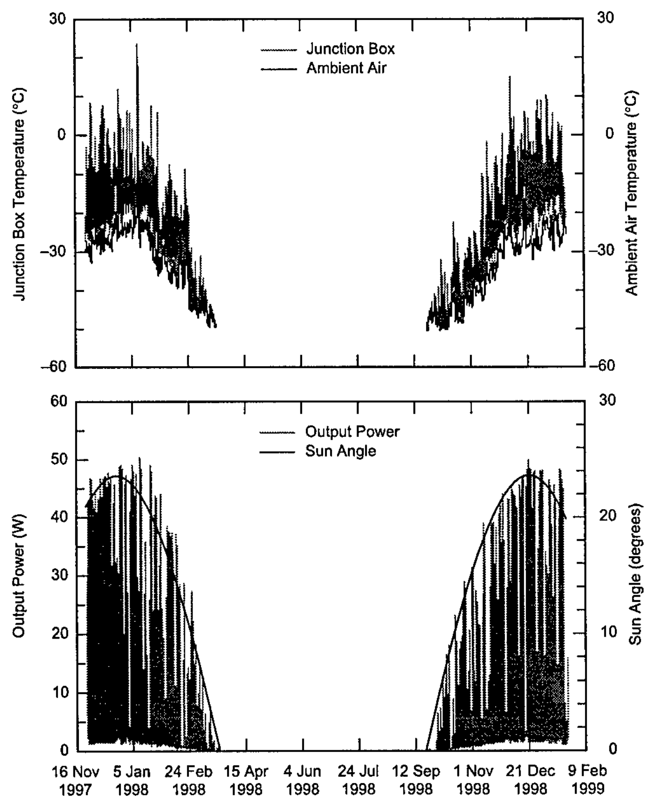

Figure A6. Performance of PV panel 2B from 25 November 1997 to 23 January 1999.

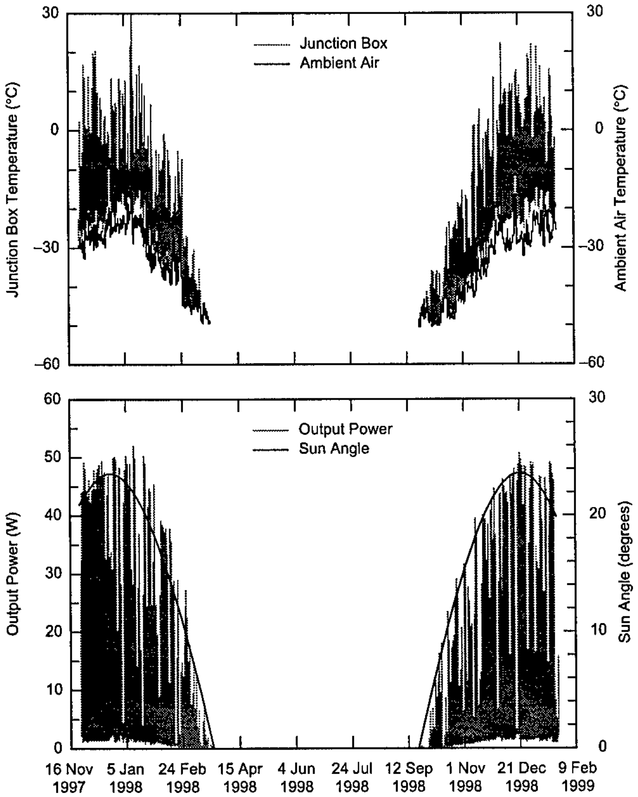

Figure A7. Performance of PV panel 2C from 25 November 1997 to 23 January 1999.

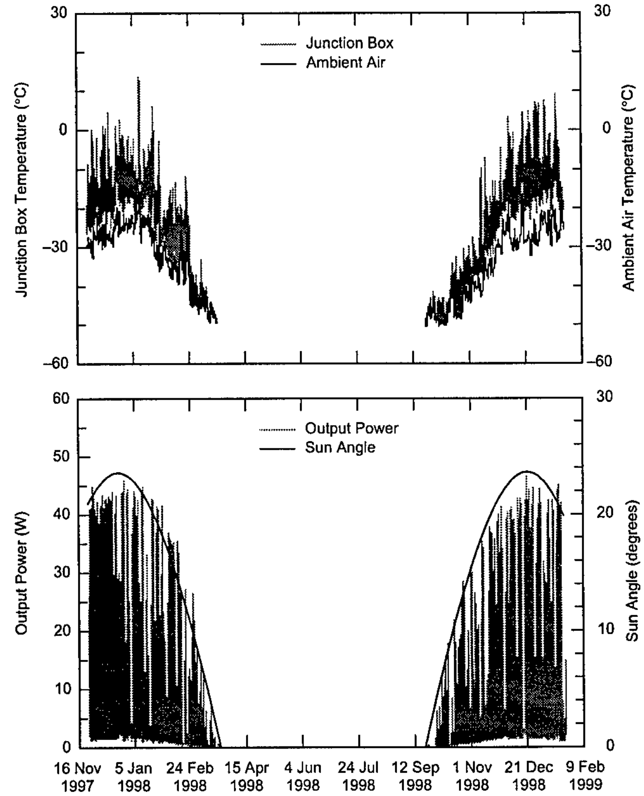

Figure A8. Performance of PV panel 2D from 25 November 1997 to 23 January 1999.

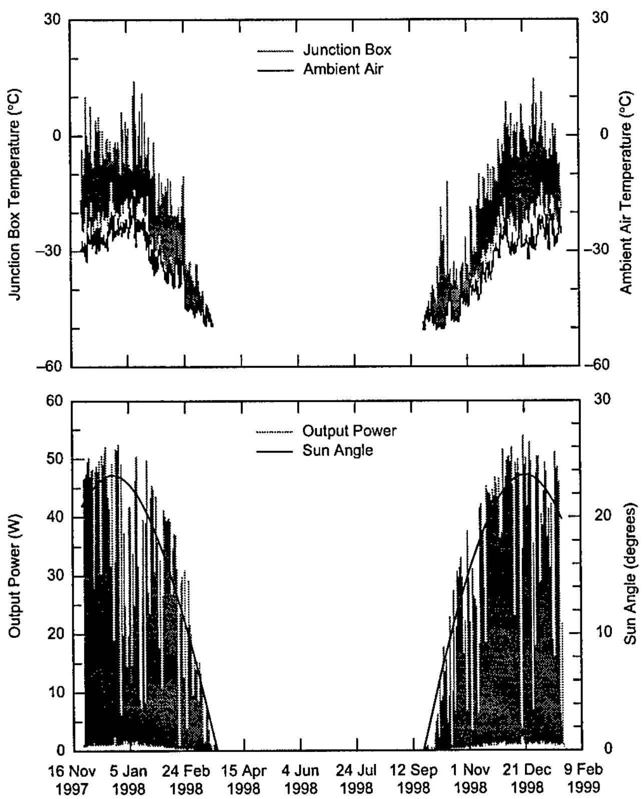

Figure A9. Performance of PV panel 3A from 25 November 1997 to 23 January 1999.

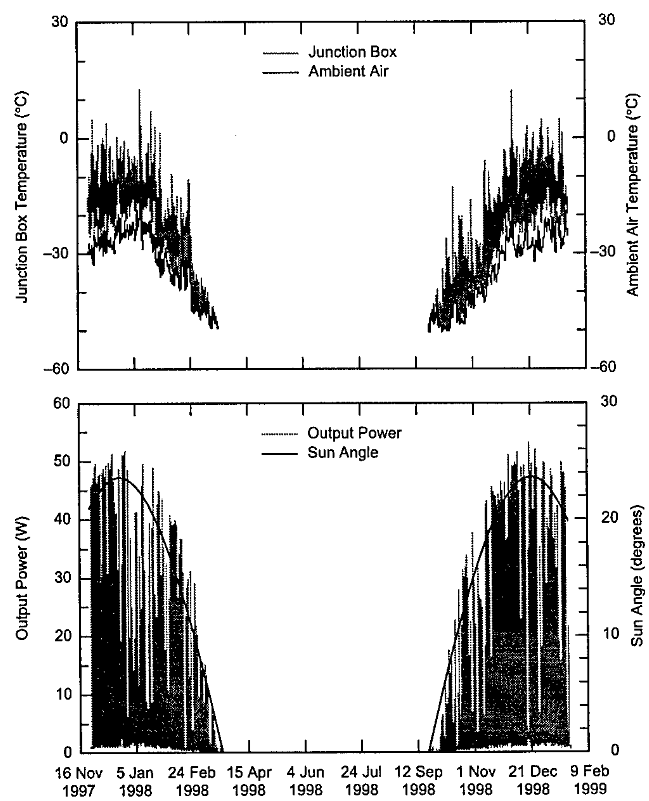

Figure A10. Performance of PV panel 3B from 25 November 1997 to 23 January 1999.

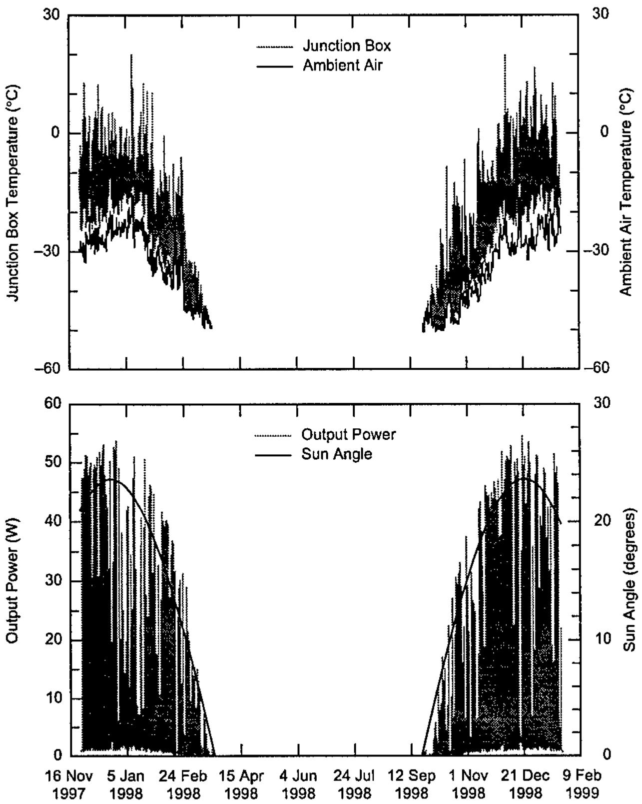

Figure A11. Performance of PV panel 3C from 25 November 1997 to 23 January 1999.

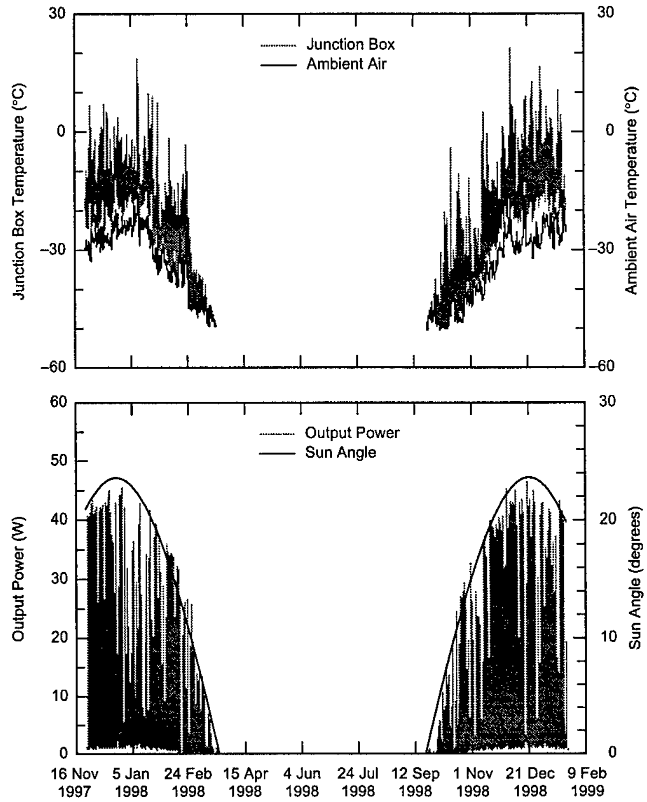

Figure A12. Performance of PV panel 3D from 25 November 1997 to 23 January 1999.

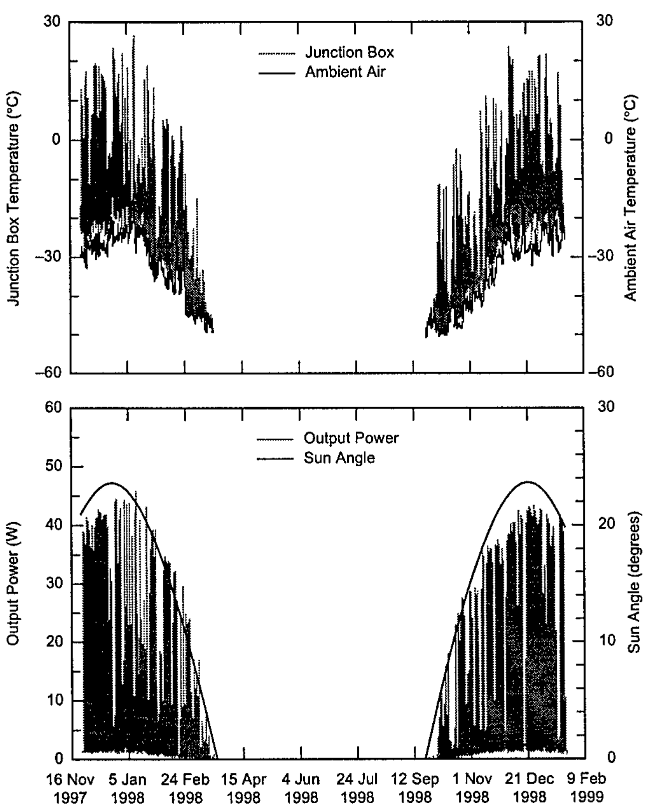

Figure A13. Performance of PV panel 4A from 25 November 1997 to 23 January 1999.

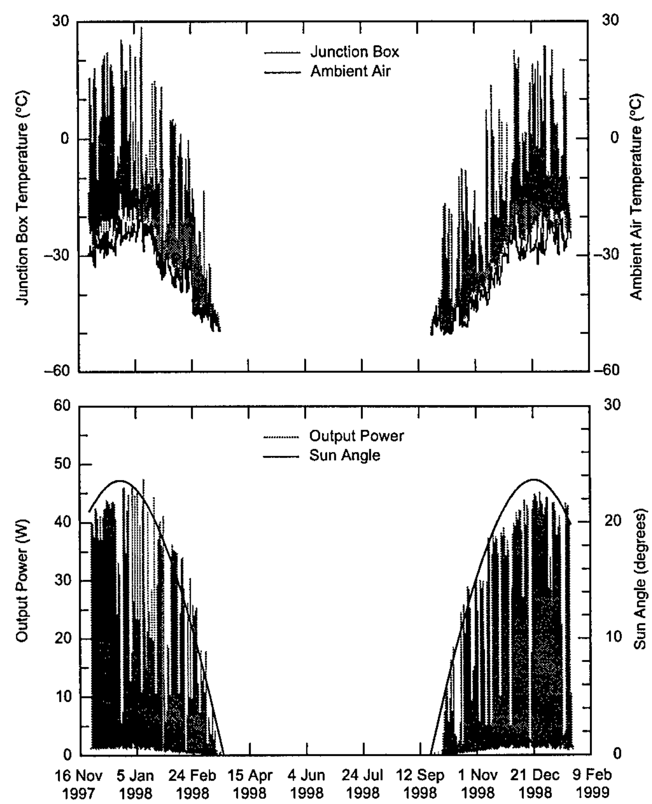

Figure A14. Performance of PV panel 4B from 25 November 1997 to 23 January 1999.

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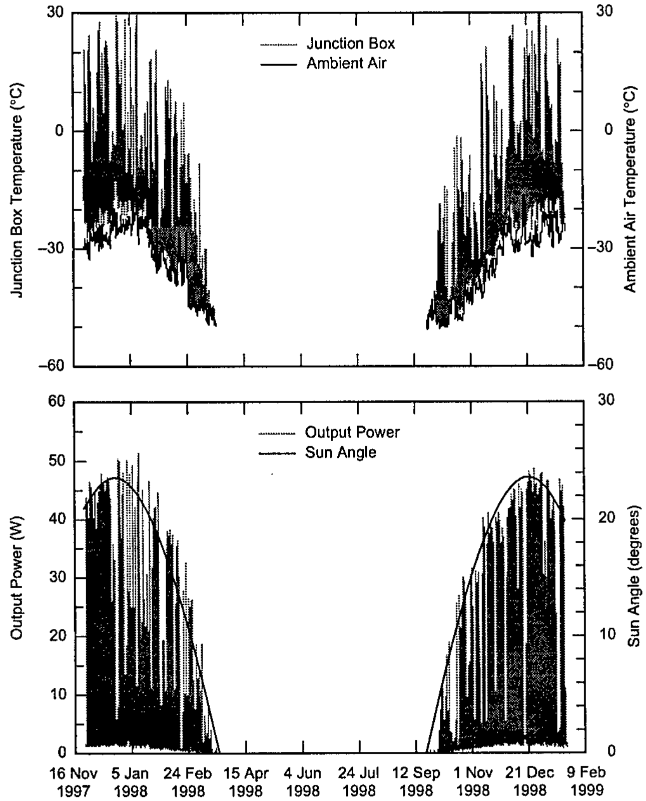

Figure A15. Performance of PV panel 4C from 25 November 1997 to 23 January 1999.

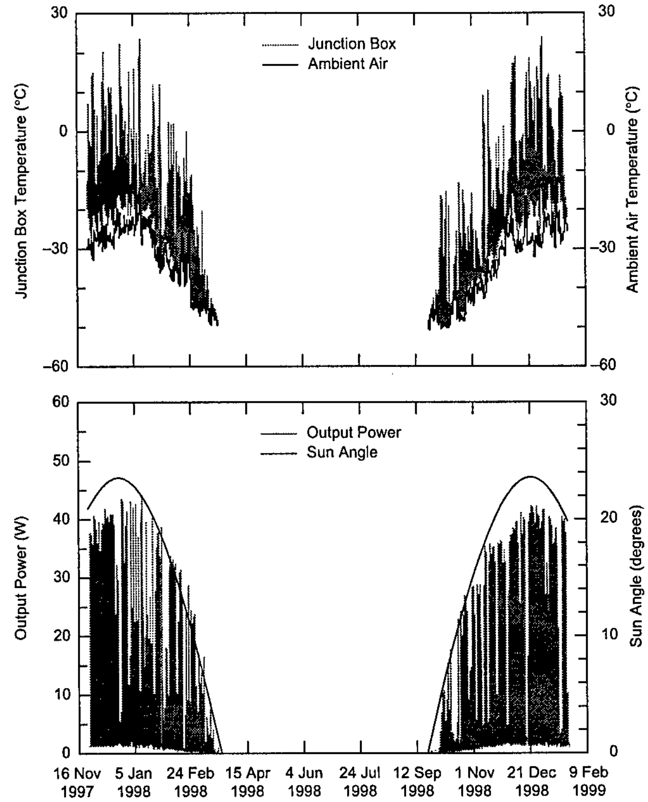

Figure A16. Performance of PV panel 4D from 25 November 1997 to 23 January 1999.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YY)*
April 2000

2. REPORT TYPE
Technical Report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Evaluation of Photovoltaic Panels at the South Pole Station

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Christopher R. Williams and John Rand

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Engineer Research and Development Center, Corps of Engineers
Cold Regions Research and Engineering Laboratory
72 Lyme Road
Hanover, New Hampshire 03755-1290

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report TR-00-4

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Science Foundation
Arlington, Virginia 22230

10. SPONSOR / MONITOR'S ACRONYM(S)

11. SPONSOR / MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

Available from NTIS, Springfield, Virginia 22161.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

For this study, commercially available photovoltaic (PV) panels of similar mechanical and electrical characteristics were procured from four manufacturers, and their structural survivability and electrical performance were evaluated in the extreme harsh environment of the South Pole, on the rooftop of the newly constructed Atmospheric Research Observatory (ARO). The PV panels were installed for 410 days. During that time, they were exposed to varying amounts of inclement weather. Temperatures ranged from a low of –70 to a high of –20°C, with average wind speeds of approximately 5 m s^{-1}, gusting to 20 m s^{-1}. Prior to removal, each PV panel was inspected to see if the harsh environment degraded the structural characteristics of the panel frame, glazing, panel backing, and junction box. The inspection showed that the PV panels had not noticeably degraded during the 410-day exposure. The electrical performance of the PV panels depended on two factors: sun angle and visibility. On days with cloud cover or windblown snow, the PV panels' output power was reduced significantly. With sun angles approaching the highest limits and visibility being high, the PV panels approached their rated output power.

15. SUBJECT TERMS
Photovoltaic panels   Solar energy   South Pole

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(include area code)*
U	U	U	U	23	

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Standard Form 298 (Rev. 8-98)
]Prescribed by ANSI Std. 239.18